Orthopaedics & Traumatology: Surgery & Research 100 (2014) S249–S254

Available online at
ScienceDirect
www.sciencedirect.com
Elsevier Masson France
EM|consulte
www.em-consulte.com/en

Workshops of the SOO (2013, Tours). Original article

The progression of lumbar curves in adolescent Lenke 1 scoliosis and the distal adding-on phenomenon

W. Lakhal*, J.-E. Loret, C. de Bodman, J. Fournier, F. Bergerault, B. de Courtivron, C. Bonnard

Service de chirurgie orthopédique pédiatrique, hôpital de Clocheville, centre hospitalier universitaire, boulevard Béranger, 37044 Tours, France

ARTICLE INFO

Keywords:
Adolescent idiopathic scoliosis
Adding-on scoliosis
Scoliosis surgery
Side-bending radiograph
Lumbar range of motion

ABSTRACT

Introduction: The postoperative deterioration of the curve below spinal fusion instrumentation resulting in a distal adding-on (AO) phenomenon in idiopathic adolescent scoliosis (IAS) frequently requires surgical revision with disappointing secondary clinical results.

Hypothesis: Analysis of AP (coronal) range of motion (cROM) and lateral (sagittal) range of motion (sROM) on dynamic (side-bending, flexion, extension) X-rays to determine the choice of the lowest instrumented vertebra (LIV) can help reduce distal adding-on. The goal of this study was to study the postoperative progression of the lumbar curve in Lenke 1 scoliosis operated on with a LIV based on dynamic X-ray results.

Materials and methods: Right-sided Lenke 1 IAS that was treated surgically by posterior arthrodesis alone with a follow-up of at least 2 years was included in the study. The following radiographic parameters were evaluated: the Cobb angles of the curves, reducibility of the curves, the apex of the scoliosis, the central sacral vertical line, the stable vertebra (SV), the neutral vertebra (NV), the distances between the CSVL and the centroids of the LIV and of the first vertebra below instrumentation, as well as the tilt of the superior endplates. sROM and cROM were determined on dynamic X-rays.

Results: Fifty IAS were evaluated/185 files. Only three cases fulfilled the criteria for AO including two that were secondary to peri- or postoperative complications. The lumbar curve presented with a loss of correction of 0.9° at one year and 1.14° at the final follow-up. None of the parameters studied were correlated to the deterioration of the lumbar curve.

Discussion: The choice of the LIV has been shown to influence the deterioration of the lumbar curve and the development of AO. The choice of the LIV based on an analysis of AP (coronal) and lateral (sagittal) range of motion seems to prevent the development of AO.

Level of evidence: 4, retrospective study.

1. Introduction

Preservation of range of motion of the lumbar spine is the main goal of treatment of Adolescent Idiopathic Scoliosis (AIS).

Thus, to preserve function, the number of lumbar vertebrae included in arthrodesis should be limited. However, in this case, patients are at an increased risk of developing the Distal Adding-On phenomenon (AO) [1].

AO is defined in the literature as the postoperative deterioration of the curve below spinal fusion instrumentation associating:

- increase in the Cobb angle of the lumbar curve;
- and/or an increase in the number of vertebrae included in this curve;
- after a minimum follow-up of one year (Fig. 1) [2];
- a deviation of more than 5 mm in the lowest instrumented vertebra (LIV) from the central sacral vertical line (CSVL) [3];
- an increase in the narrowing of the first vertebra below instrumentation of more than 5°.

The incidence of AO in the literature is between 2 and 51% depending on the studies (Lehman: 2% [4]; Matsumoto: 18.8% [5]; Suk: 33.3% [6]; Wang: 51.1% [2]). This complication frequently requires surgical revision with disappointing clinical results.

To limit the risk of this complication, we determined the LIV for arthrodesis on dynamic AP (coronal) and lateral (sagittal) X-rays.

* Corresponding author. Tel.: +33 6 11 44 55 10.
E-mail address: walidlak@hotmail.com (W. Lakhal).

http://dx.doi.org/10.1016/j.otsr.2014.03.012
1877-0568/

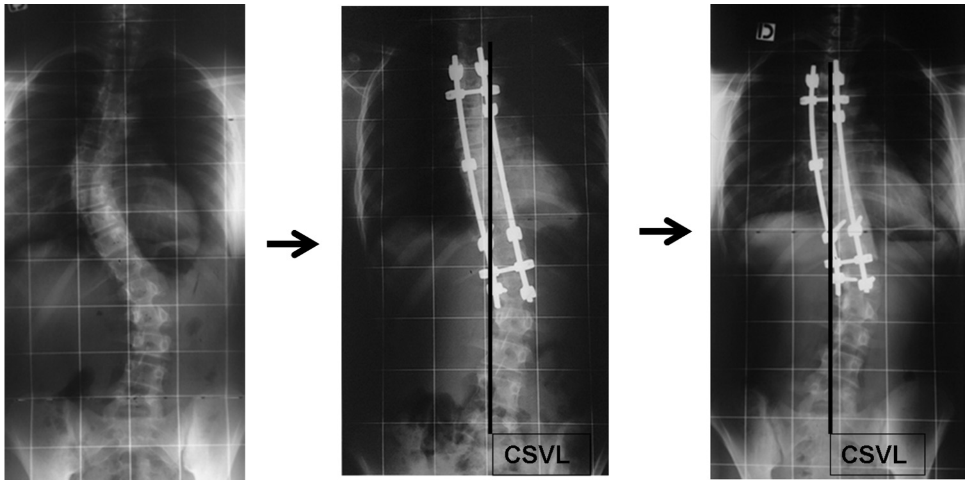

Fig. 1. Distal adding-on was defined as a progressive increase in the number of vertebrae included within the primary curve distally combined with either an increase of more than 10 mm in the deviation of the first vertebra below the instrumentation from CSVL (center sacral vertical line) or an increase of more than 5° in angulation of the first disc below the instrumentation at 1 year follow-up.

The main goal of this study was to evaluate the deterioration of lumbar curves after posterior arthrodesis of Lenke 1 scoliosis and to determine the incidence of AO [7].

The secondary goals were to study the preoperative sagittal (sROM) and coronal (cROM) range of motions of the first intervertebral disc below instrumentation and study the different risk factors of AO that have been mentioned in the literature (choice of LIV, age, bone maturity).

2. Materials and methods

This was a retrospective, single center, non-comparative study.

The files of patients treated surgically for IAS were taken from the database of our institution. All procedures were performed by a senior surgeon specialized in scoliosis between 1996 and 2009. The indication for surgery was based on conventional criteria of flexibility and the progression of scoliosis. The choice of the level of instrumentation was based on a radiographic assessment including standing AP (coronal) and lateral (sagittal) X-rays and dynamic AP and lateral X-rays.

Patients with Lenke 1 IAS treated surgically by posterior arthrodesis with at least 2 years of follow-up were included in the study [7].

IAS other than Lenke 1, and IAS requiring associated anterior surgery and left convex Lenke 1 IAS were excluded from the study.

The preoperative radiographic assessment included standing AP (coronal) and lateral (sagittal) X-rays as well as dynamic AP and lateral X-rays.

The preoperative choice of the level of instrumentation was based on the following:

- dynamic X-rays and analysis of flexibility – sROM and cROM;
- use of a hybrid instrumentation technique by posterior arthrodesis alone.

A postoperative follow-up assessment was performed on day 45, at 3 months, 6 months and 1 year, then yearly, with static X-rays.

Radiographic parameters included: the Cobb angle of the major thoracic curve and the lumbar curve (Fig. 2A), reducibility of these curves on dynamic X-rays, the apex of the scoliosis, the CSVL, the stable vertebra (SV) and the neutral vertebra (NV) (Fig. 2A).

The sROM and cROM of the first vertebra below instrumentation were measured on dynamic X-rays (Fig. 2C).

The distances between the CSVL and the centroid of the LIV (Fig. 2B) and between CSVL and the first vertebra below instrumentation (LIV + 1) were measured (mm) (Fig. 2B). These values were considered to be positive when the centroid had deviated to the right and negative when they were found to the left of the CSVL.

The tilt of the superior endplate of LIV and LIV + 1 were measured (Fig. 2B). The value was considered to be positive if the endplate was tilted to the right.

2.1. Statistical analysis

Statistical analyses were performed with the Chi^2 and Fisher-Yates for analysis of comparisons. Analysis of variance ANOVA was performed with Statview® software.

Table 1
Demographical data.

	n	(%)
Mean Age (years)	15.1	
0–13 years	5	10
13–15 years	34	68
> 15 years	13	26
Sex		
Female	46	92
Male	4	8
Risser index		
1	4	8
2	11	22
3	12	24
4	19	38
5	4	8
Follow-up (months) (range)	52.5 (24–126)	
24–48 months	23	46
48–72 months	17	34
> 72 months	10	20
Lenke 1 Scoliosis		
A	20	40
B	19	38
C	11	22
Lenke 1 Scoliosis		
–	4	8
N	37	74
+	9	18

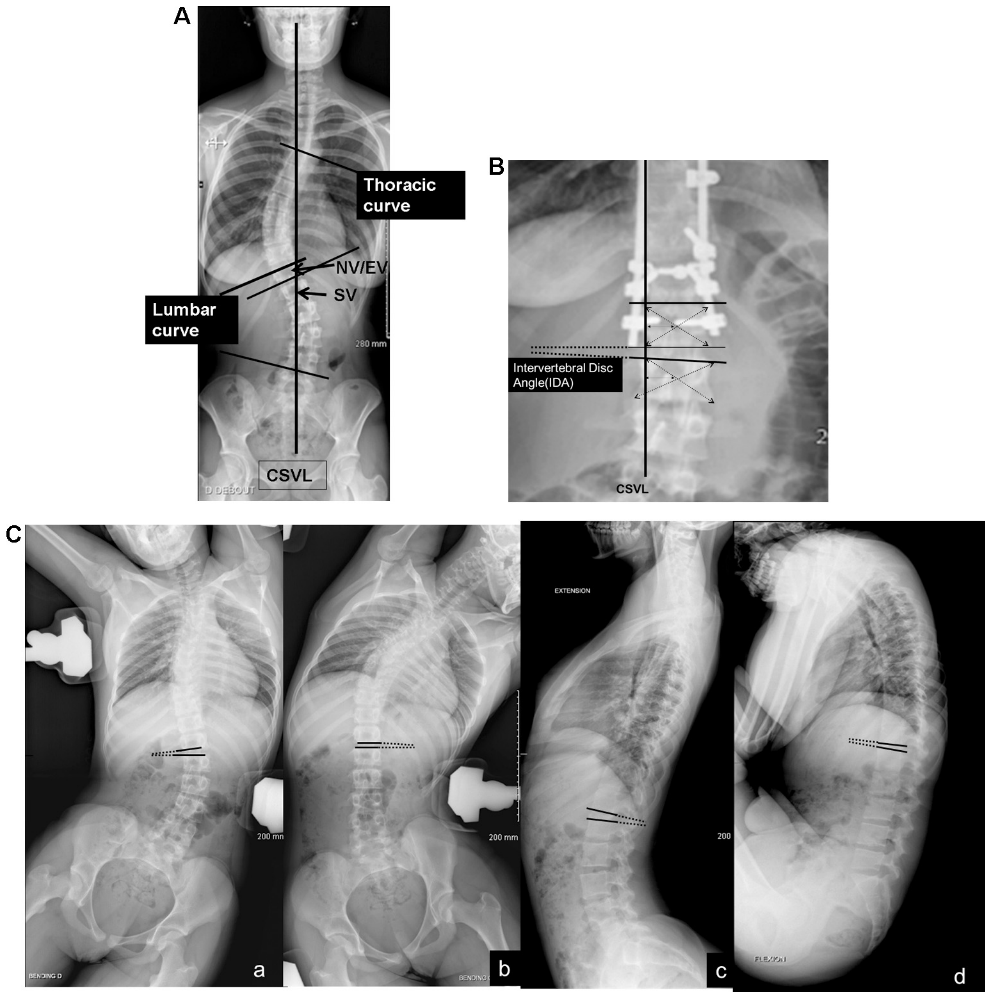

Fig. 2. A. Radiographic parameters: CSVL (center sacral vertical line) is the vertical line which bisects proximal sacrum; EV (end vertebra) which is the first vertebra whose inferior surface is tilted maximally toward the concavity of the curve; NV (neutral vertebra) is the first vertebra in caudad direction without axial rotation; SV (stable vertebra) is the most proximal lower thoracic or lumbar vertebra most closely bisected by the center sacral vertical line. LIV is the lowest instrumented vertebra; LIV + 1 is the first vertebra below LIV. B. Deviation of a vertebra from CSVL (center sacral vertical line): In frontal radiograph, Four contour tangents for each vertebral body are constructed, and two diagonal lines are drawn, each connecting two corners of the vertebra, where adjacent contour tangents intersect. The intersection of these two lines is the vertebral centroid. The distance between the vertebral centroid and the CSVL was measured. C. Determination of the lowest instrumented vertebra (LIV) for a patient with single right thoracic scoliosis. The discal range of motion (ROM) was defined as the cobb angle formed by lines along the inferior end plate of the cephalad vertebral body and along the superior end plate of the caudad vertebral body. The coronal range of motion (cROM) was measured in both right and left side-bending radiographs. The sagittal range of motion (sROM) was measured in both full flexion and full extension radiographs: a: on the right side-bending radiograph, the intervertebral disc angle T12L1 was open on the left; b: on the left side-bending radiograph, the intervertebral disc angle T12L1 was neutral; c: on the full extension radiograph, the T12L1 disc was open; d: on the full flexion radiograph, the disc was kyphotic. T12L1 disc was flexible. T12 was chosen as LIV.

3. Results

3.1. Demographic data

Of 185 cases reviewed, 62 fulfilled inclusion criteria.

Twelve patients were not included because of missing data, there was no AO in any of these patients. The cohort included 46 girls and 4 boys mean age 15.1 years old (12–20). The Risser index was between 1 and 3 in 54% of the cases (Table 1). Mean follow-up was 52.5 months (24–126 months) (Table 1) with a mean age at the final follow-up of 19.5 years old (14.5–29.4) (Table 1). Only 3 patients fulfilled criteria for AO.

3.2. Analysis of radiological data

The 3 subtypes of Lenke 1 IAS (A, B and C) were evenly distributed in the cohort (Table 1). The analysis of thoracic kyphosis showed N-subtype in 74%, corresponding to the same classification [7].

The thoracic curve was a mean 52° (40–70°) and shown to reducible by 52% (17–91%) on dynamic X-rays. The mean Cobb angle of the lumbar curve was 30° (14–45°) reducible by 100.2% (Table 2).

The distribution of the end vertebrae (EV), SV, and NV are shown in Table 2.

The mean cROM of the first vertebra below instrumentation was 10° (5–14°).

The mean sROM of the first vertebra below instrumentation was 9° (0–17°).

The LIV was L1 in 68% of cases (Table 3).

The distance between the CSVL and the centroid of LIV and LIV + 1, as well as the tilt of the superior endplate of LIV and LIV + 1 are found in Table 3.

The thoracic curve was reduced by 64% to 19° (4–48°) and the lumbar curve by 69% to 9° (0–22°).

Loss of angular correction of 0.9° at one year of follow-up and 1.86° at the final follow-up was observed for the major curve.

Loss of correction of 0.9° was found for the lumbar curve at one year of follow-up and of 1.14° at the final follow-up (Table 3).

Table 2
Preoperative radiographic data.

Thoracic curve (cobb angle) (°)	
Static (range)	52.32 (40–70)
Side bending	24.82 (3–50)
Flexibility (range) (%)	53.49 (17–91.47)
Lumbar curve (cobb angle) (°)	
Static (range)	30.38 (14–45)
Side bending	1.1 (−17–18)
Flexibility (range) (%)	100.2 (50–200)
Levels of AV (n)	
T6	1
T7	2
T8	19
T9	20
T10	7
T11	1
Levels of EV (n)	
T10	2
T11	13
T12	23
L1	11
L2	1
Levels of SV (n)	
T11	5
T12	8
L1	20
L2	10
L3	7
Levels of NV (n)	
T11	9
T12	31
L1	6
L2	4
Distance between CSVL (mm)	
AV centroïd	47,7 (10–84)
LIV centroïd	5,5 (−24–40)
LIV + 1 centroïd	−3,8 (−27–22)
Tilt LIV(°)	19,7 (−21–33)
Tilt LIV + 1(°)	10,7 (−12–29)
cROM(°)	10,1 (5–14)
IDA left	2 (−1–6)
IDA right	8,1 (4–12)
sROM(°)	8,9 (0–17)
IDA flexion	2,4 (−6–8)
IDA extension	6,5 (−1–15)

AV: apical vertebra; EV: end vertebra; SV: stable vertebra; NV: neutral vertebra; CSVL: center sacral vertical line; cROM: coronal range of motion; sROM: sagittal range of motion; IDA: intervertebral disc angle (left: on left side-bending radiograph; right: on right side-bending radiograph; flexion: on full flexion radiograph; extension: on full extension radiograph); LIV is the lowest instrumented vertebra; LIV + 1 is the first vertebra below LIV; the Tilt represents the tilt of the superior endplate of the vertebra.

None of the preoperative or postoperative parameters studied (apex of the scoliosis, size of the curves, CSVL, SV, NV, sROM of the first intervertebral disc below instrumentation, cROM of the first intervertebral below instrumentation, distance CSVL — centroid of the LIV, distance CSVL — centroid of LIV + 1, tilt of the superior endplate of LIV and LIV + 1) were found to be significant in relation to the progression of the lumbar curve.

The 1-year postoperative results of the tilt of the superior endplate of the LIV as well as the distance between the CSVL – and the centroid of the LIV + 1 were close to being significant; ($P = 0.07$) and ($P = 0.08$) respectively.

Three patients fulfilled the criteria of AO including 2 who required surgical revision at 8 and 36 months.

The first case was a 13-year-old patient, Risser 2, instrumented fusion to T12.

The thoracic curve was 64°, reducible to 40° on dynamic X-rays and reduced to 48° postoperatively. The lumbar curve was 32° reducible to 3° and reduced to 22° postoperatively. The surgical procedure was stopped when somatosensory and motor evoked potentials were found to be interrupted. Neurological recovery occurred in several days and the procedure was begun again one month later with arthrodesis without reduction. Reduction was necessarily insufficient and instrumentation should have been extended distally. A 12° increase in the lumbar curve and a 14 mm increase in the LIV/CSVL distance were observed.

The second case was a 13-year-old patient, Risser 2, instrumented spinal fusion to L1.

The thoracic curve was 46° reducible to 22° on dynamic X-rays and reduced to 30° postoperatively.

The lumbar curve was 32° reducible to 6° on dynamic X-rays and reduced to 17° postoperatively.

The angle of the first disc below instrumentation gradually increased from 10 to 16°, the lumbar curve increased from 17 to 28° and the distance between L1 and CSVL increased by 9 mm at 36 months of follow-up.

The sROM and cROM of L1/L2 were satisfactory on preoperative dynamic X-rays. This failure can be explained by non-union and failure of a screw. The patient underwent revision surgery 36 months after the initial fusion and instrumentation was extended to L3.

Although they corresponded to the definition of AO, in these 2 cases the progression of the lumbar curve was associated with a peri- or postoperative complication.

The third case was a 13-year-old patient, Risser 2, instrumented spinal fusion to L1 (Fig. 3).

The thoracic curve was 50° reducible to 26° on dynamic X-rays and reduced to 15° postoperatively.

The lumbar curve was 43° reducible to 5° on dynamic X-rays and reduced to 13° postoperatively.

The patient presented with radiological deterioration with an increase in the lumbar curve from 13 to 19° and an increase in the angle of the first vertebra below instrumentation from 9 to 17° at postoperative month 8. The distance between the CSVL and the centroid of LIV increased by 6 mm from 32 to 38 mm. The distance between the CSVL and the centroid of LIV + 1 increased by 11 mm from 29 to 40 mm.

Arthrodesis was extended from L1 to L2 in this patient.

The retrospective analysis of this case of AO, which was not associated with a peri- or postoperative complication, showed a cROM of 11° but an sROM of 0°. The first vertebra below instrumentation was therefore not flexible on the sagittal plane.

4. Discussion

In this study the choice of LIV was based on coronal and sagittal flexibility of the first disc below instrumentation. If these criteria had been respected in all cases, there would have been no AO in our study. There was no significant postoperative deterioration of the lumbar curve in our study.

Theoretically, the ideal surgical technique should associate optimal correction of scoliosis, prevent the postoperative progression of the lumbar curve and preserve flexibility of the spine below instrumentation.

The clinical impact of AO is not known, but worsening of the initial lumbar curve can result in decompensation of coronal balance and disappointing results.

In the present retrospective study of 50 patients who underwent surgery for Lenke 1 IAS, there was a mean postoperative loss of correction of the lumbar curve of 0.9° at 1 year and 1.2° at the final follow-up.

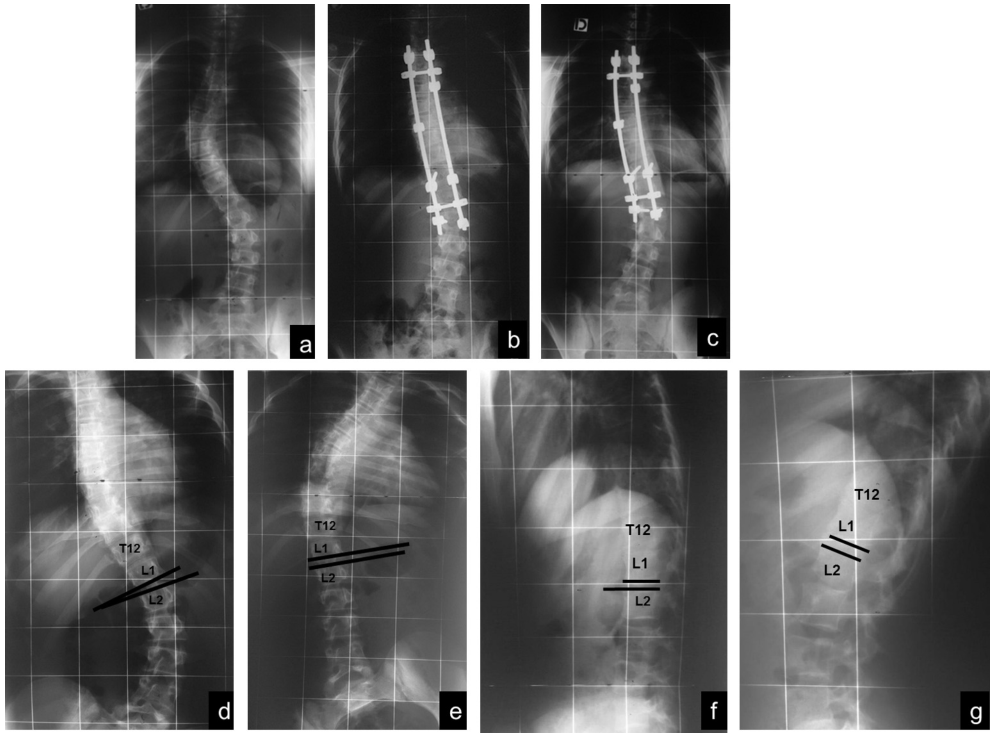

Fig. 3. A 13-year-old female with adding-on: a: before surgery. Single right thoracic Lenke 1-A scoliosis; b: at 1,5 months follow-up, radiograph showed that L1 deviation from the center sacral vertical line was 33 mm and Cobb angle of the lumbar curve was 13°; c: at 8 months follow-up, L1 deviation and Cobb angle increased progressively to 38 mm and 19°. The intervertebral disc angle immediately below the LIV increased of 8°; d: on the right side-bending radiograph, the intervertebral disc angle L1L2 was open on the left; e: on the left side-bending radiograph, the intervertebral disc angle L1L2 was neutral; f: on the full flexion radiograph, the L1L2 disc was neutral; g: on the full extension radiograph, the disc was neutral. The sROM was non-existent. L1L2 disc was flexible on side-bending radiographs but not flexible on full flexion-extension radiographs. L1 was chosen as LIV but it should have been L2.

The physiopathology of AO is clearly multifactorial, associating factors that cannot be controlled by the surgeon, such as the natural progression of a degenerative spine disease and that can be controlled, such as the choice of the level of the limits of arthrodesis.

There are very few studies on the risk factors of AO. Wang et al. found that a deviation of the preoperative center of the first disc below instrumentation from the CSVL of more than 10 mm was an independent predictive factor of AO [2]. They described factors that were non-significantly correlated to the development of AO. This included age, which is directly related to bone maturity, the difference in level between SV and LIV and the difference in level between EV and LIV, which are directly associated with the choice of LIV. After analyzing several strategies for the choice of LIV, these authors recommended choosing the first vertebra in a cephalad direction from the sacrum with a deviation of more than 10 mm from the CSVL.

The optimal choice of LIV is still a subject of controversy and debate. Suk et al. recommend focusing the choice on the NV [6].

Table 3
Postoperative radiographic data.

Follow-up	1.5 months	12 months	Final follow-up
Age (years)	15.25 (12.2–20.1)	17.1 (12–22)	19.5 (14.5–29.4)
Levels of LIV (n)			
T12	4		
L1	34		
L2	11		
L3	1		
Cobb angle of thoracic curve (range) (°)	19.2 (4–48)	20.3 (6–48)	21 (6–48)
Reduction (%)	63.7 (33–91)		
Cobb angle of lumbar curve (range) (°)	9.28 (0–22)	10.2 (0–23)	10.4 (0–34)
Reduction (%)	68.6 (31–100)		
Distance between CSVL (range)			
AV centroïd (mm)	9,7 (−26–40)	13,7 (−21–54)	14,9 (−14–59)
LIV centroïd (mm)	−4,9 (−33–23)	−2,7 (−38–27)	−1 (−39–26)
LIV + 1 centroïd (mm)	−7,8 (−31–10)	−5,9 (−40–14)	−4,6 (−36–15)
Tilt LIV (°)	4 (−6–19)	4,7 (−7–22)	4,9 (−7–25)
Tilt LIV + 1 (°)	1,7 (−16–19)	2,6 (−18–28)	3,6 (−15–28)

LIV: lowest instrumented vertebra; CSVL: center sacral vertical line; AV: apical vertebra; LIV + 1 is the first vertebra below LIV; the Tilt represents the tilt of the superior endplate of the vertebra.

They observed an increased risk of AO when LIV was proximal to the NV by more than 2 vertebrae. If the NV was located less than 2 levels from the end vertebra (EV) they recommend extending arthrodesis to the NV. Matsumoto et al. reported that postoperative apical translation of the thoracic curve and deviation of the LIV in relation to the CSVL influenced the development of AO [5].

Cho et al. studied numerous parameters including L4 vertebral tilt, preoperative thoracic curves and lumbar curves, coronal reducibility and flexibility [8]. They only found 2 variables that were significant predictive factors for the development of AO: age ($P = 0.002$) and the Risser index ($P = 0.004$).

None of the parameters in our study were correlated to a worsening of the lumbar curve.

The statistical results in our study, which were the closest to those in the literature, were the tilt of the superior endplate of LIV at one year ($P = 0.07$), and the distance between CSVL and LIV + 1 ($P = 0.08$).

The different studies in the literature have reported the results of the choice of the LIV but do not defend the strategy applied to each patient group [2,3,5,6,8].

The strategy for choosing the LIV in our study took into account the degree and reducibility of the lumbar curve. Indeed, the lumbar curve was not instrumented if it was less than 45° and could be reduced by more than 50%.

The choice of LIV was based on an evaluation of the flexibility of the intervertebral discs on AP (coronal) X-rays (cROM) as recommended by Ni et al. [9]. The mean cROM of the first disc below instrumentation was 10° (4–18°). The sROM was also considered and measured on lateral (sagittal) X-rays. The mean sROM of the first vertebra below instrumentation was 9° (0–17°). The LIV was therefore the vertebra above the first flexible intervertebral disc.

The angle of the discs on static X-rays had to at least be neutralized on AP (coronal) and lateral (sagittal) dynamic X-rays.

This original strategy is described for the first time in the present study. The low incidence of AO in this study may be due to our strategy of instrumentation based on preoperative segmental flexibility.

The retrospective analysis of the only case of AO that was not associated with a peri- or postoperative complication showed a cROM of 11° but an insufficient sROM of 0°.

The first vertebra below instrumentation was therefore not flexible on the sagittal plane.

Therefore, our strategy of instrumentation based on flexibility was not applied in this case.

Thus we only observed one case of distal adding on in this study, which is the minimum incidence reported in the literature. However, this was a retrospective study with a small cohort of patients. All of the patients in our study had not reached complete bone maturity but they were at least Risser 4 with a mean age of 19.5. The risk of later distal adding-on is low but not inexistent.

5. Conclusion

In Lenke 1 scoliosis, the choice of LIV is strongly correlated with the progression of the lumbar curve below instrumentation and with distal AO. The choice of LIV based on an analysis of the AP (coronal) as well as lateral (sagittal) range of motion seems to prevent the development of this complication and deterioration of the lumbar curve. These observations are encouraging and need to be confirmed in further studies.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References

[1] Lykissas MG, Crawford AH, Jain VV. Complications of surgical treatment of pediatric spinal deformities. Orthop Clin North Am 2013;44:357–70.
[2] Wang Y, Hansen ES, Hoy K, et al. Distal adding-on phenomenon in Lenke 1A scoliosis: risk factor identification and treatment strategy comparison. Spine 2011;36(14):1113–22.
[3] Wang Y, Bunger CE, Zhang Y, et al. Distal adding-on in Lenke 1A scoliosis: how to more effectively determine the onset of distal adding-on. Spine 2013;38(6):490–5.
[4] Lehman Jr RA, Lenke LG, Keeler KA, et al. Operative treatment of adolescent idiopathic scoliosis with posterior pedicle screw-only constructs: minimum three-year follow-up of one hundred fourteen cases. Spine 2008;33(14):1598–604.
[5] Matsumoto M, Watanabe K, Hosogane N, et al. Postoperative distal adding-on and related factors in Lenke type 1A curve. Spine 2013;38:737–44 [Epub ahead of print].
[6] Suk SI, Lee SM, Chung ER, et al. Selective thoracic fusion with segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis: more than 5-year follow-up. Spine 2005;30(14):1602–9.
[7] Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am 2001;83-A(8):1169–81.
[8] Cho RH, Yaszay B, Bartley CE, et al. Which Lenke 1A curves are at the greatest risk for adding-on... and why? Spine 2012;37(16):1384–90.
[9] Ni HJ, Su JC, Lu YH, Zhu XD, He SS, Wu DJ, et al. Using side-bending radiographs to determine the distal fusion level in patients with single thoracic idiopathic scoliosis undergoing posterior correction with pedicle screws. J Spinal Disord Tech 2011;24:437–43.